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(71) Applicant *(for all designated States except US)*: **MOCON, INC.** [US/US]; 7500 Boone Avenue North, Minneapolis, Minnesota 55428 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **MAYER, Daniel W.** [US/US]; 19403 Tri-oaks Circle, Wyoming, Minnesota 55092 (US). **ASCHEMAN, Timothy A.** [US/US]; 9819 226th Lane NW, Elk River, Minnesota 55330 (US).

(74) Agents: **LEWEN, Elizabeth D.** et al.; Sherrill Law Offices, PLLC, 4756 Banning Avenue, Suite 212, White Bear Lake, Minnesota 55110 (US).

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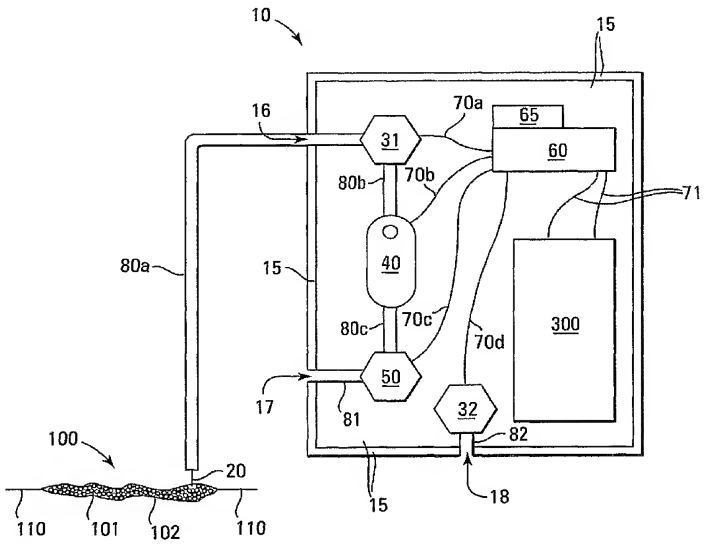
(54) **Title:** INSTRUMENT AND METHOD FOR DETECTING AND REPORTING THE SIZE OF LEAKS IN HERMETICALLY SEALED PACKAGING



(57) **Abstract:** An instrument for detecting leaks in a hermetically sealed package. The instrument includes (i) a hollow needle, (ii) a mass flow rate sensor in sealed fluid communication with the lumen defined by the hollow needle, and (iii) a vacuum pump. The vacuum pump is in fluid communication with the lumen defined by the needle for evacuating gas from the hermetically sealed package, and in fluid communication with the mass flow rate sensor for directing mass flow from the evacuated package into operable contact with the mass flow rate sensor so as to permit sensing of any continuing mass flow from the evacuated package. The instrument may further include an oxygen sensor in sealed fluid communication with the lumen defined by the hollow needle for analyzing the oxygen concentration of the gas within the hermetically sealed package.

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INSTRUMENT AND METHOD FOR DETECTING AND REPORTING THE SIZE OF LEAKS IN HERMETICALLY SEALED PACKAGING

FIELD OF INVENTION

[0001] The invention relates to instruments and techniques for detecting leaks in hermetically sealed packaging.

BACKGROUND

[0002] Products susceptible to spoilage, such as processed foods, nuts and sliced fruits and vegetables, are often placed in hermetically sealed packaging which has been flushed with an inert gas, such as nitrogen or argon, to achieve an oxygen concentration within the packaging of less than about 3% and thereby prolong the shelf-life of the product. Such packaging is commonly known as controlled atmosphere packaging (CAP) or modified atmosphere packaging (MAP).

[0003] Leaks in the packaging can significantly reduce the anticipated shelf life, resulting in undesired spoilage. Hence, proper quality control efforts for CAP/MAP typically involve at least periodic testing of packaging to determine if the packaging has any leaks.

[0004] A variety of instruments and methods are known for detecting leaks in hermetically sealed packaging. Leak detection typically involves the creation of a pressure differential between the pressure inside the packaging (internal pressure) and the pressure outside the packaging (external pressure) - such as by compressing the packaging or pulling a vacuum in the atmosphere surrounding the packaging, followed by the detection of any change in a given variable which could be correlated to the presence of a leak in the packaging. Specific examples include submersion of the packaging into a liquid and detecting any liquid within the packaging (United States Patent No. 6,763,702 issued to Allen Chien et al.), squeezing of the packaging and detecting of any pressure decay (United States Patent No. 6,427,524 issued to Frank Raspante et al.), squeezing the packaging and detecting any volume decay (United States Patent No. 5,533,385 issued to William Frievalt) and placing the packaging within a vacuum chamber and detecting any loss of vacuum (United States Patent. No. 5,150,605 issued to Edwin Simpson).

[0005] While each of these instruments and techniques are generally effective for detecting leaks in hermetically sealed packaging, a substantial need continues to exist for a quick, easy, inexpensive and accurate instrument and technique for detecting leaks in hermetically sealed packaging. A need also exists for such an instrument which could provide some indication of the size and/or location of the leak.

SUMMARY OF THE INVENTION

[0006] A first aspect of the invention is an instrument for detecting and reporting the size of a leak in hermetically sealed packaging. The instrument includes (A) a needle having a lumen, (B) a vacuum pump, (C) a mass flow rate sensor, (D) a first pressure sensor operative for sensing an external pressure on the hermetically sealed packaging and transmitting an external pressure signal, (E) a second pressure sensor for sensing pressure within the retention chamber defined by the packaging and transmitting an internal pressure signal, (F) a display device, (G) a user input device, (H) a memory device, and (I) a processor. The needle is operable for perforating the hermetically sealed packaging so as to place the lumen of the needle in fluid communication with a retention chamber defined by the packaging. The vacuum pump is in fluid communication with the lumen defined by the needle for evacuating gaseous content from the hermetically sealed packaging to form an evacuated retention chamber. The mass flow rate sensor is in sealed fluid communication with the lumen defined by the needle for sensing a mass flow rate pulled through the lumen from the evacuated retention chamber by the vacuum pump and transmitting a mass flow rate signal. The memory device receives and stores a value for the fluid viscosity of the external gas, a value for the packaging wall thickness, and a value for at least one packaging seal length. The processor is interconnected and programmed to receive the mass flow rate signal, receive the external pressure signal, receive the internal pressure signal, communicate with the memory device to obtain the fluid viscosity value, packaging wall thickness value and packaging seal length value, calculate a first hole size value for a hole through the packaging wall utilizing Pouseuill's Law and the value for the packaging wall thickness, calculate a second hole size value for a hole through at least one seal utilizing Pouseuill's Law and the value for at least one seal length, and display at least one of the first and second hole size values.

[0007] A second aspect of the invention is a computerized method for detecting a leak in hermetically sealed packaging and reporting the size of the leak. The method includes the steps of (A) perforating the hermetically sealed packaging so as to place a lumen in fluid communication with a retention chamber defined by the packaging, (B) evacuating a gaseous content from the retention chamber through the lumen so as to form an evacuated retention chamber, (C) sensing mass flow rate through the lumen from the evacuated retention chamber, (D) sensing an external pressure of a gas surrounding the evacuated retention chamber, (E) sensing an internal pressure within the evacuated retention chamber, (F) inputting into electronic memory (i) a fluid viscosity value for the external gas, (ii) a value for the thickness of the packaging walls, and (iii) a value for the length of at least one seal, (G) calculating a first hole size value of a hole through the packaging wall from the sensed and input values utilizing Pouseuill's Law and the value for the thickness of the packaging walls, (H) calculating a second hole size value of a hole through at least one seal from the sensed and input values utilizing Pouseuill's Law and the value for the length of at least one seal, and (I) reporting at least one of the first and second hole size values.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Figure 1 is a front view of one embodiment of the invention depicted with an evacuated flexible packaging.

[0009] Figure 2 is a front view of the invention shown in FIG 1 with the cover of the housing removed to facilitate viewing of the internal components.

[0010] Figure 3 is an enlarged cross-sectional side view of the distal end of the needle shown in FIG 1.

[0011] Figure 4 is an enlarged top view of one corner of a hermetically sealed packaging with a hole through the seal.

[0012] Figure 5 is an enlarged cross-sectional side view of one end of a hermetically sealed packaging with a hole through the packaging wall.

DETAILED DESCRIPTION OF THE INVENTION INCLUDING A BEST MODE

Nomenclature

10	Instrument
15	Housing
16	Inlet Port Through the Housing
17	Outlet Port Through the Housing
18	Access Port Through the Housing
20	Needle
21	Distal End of Needle
29	Lumen of Needle
31	First Pressure Sensor
32	Second Pressure Sensor
40	Vacuum Pump
50	Mass Flow Rate Sensor
60	Processor
65	Memory
70	Collective Reference to Leads 70a, 70b, 70c and 70d.
70a	Lead from the First Pressure Sensor to the Processor
70b	Lead from the Second Pressure Sensor to the Processor
70c	Lead from the Vacuum Pump to the Processor
70d	Lead from the Mass Flow Rate Sensor to the Processor
71	Leads from the Processor to the Battery
80	Collective Reference to Tubing 80a, 80b and 80c
80a	Length of Tubing Interconnecting the Needle and the First Pressure Sensor
80b	Length of Tubing Interconnecting the First Pressure Sensor and the Vacuum Pump
80c	Length of Tubing Interconnecting the Vacuum Pump and the Mass Flow Rate Sensor
81	Length of Tubing from the Mass Flow Rate Sensor to the Exit Port through the Housing
82	Length of Tubing from the Second Pressure Sensor to the Access Port through the Housing
90	User Interface Components
91	Power Button

92 Data Entry Device
93 Display Device
100 Packaging
100a Thickness of Packaging Wall
101 Solids Content of Packaging
102 Gaseous Content of Packaging
109 Retention Chamber Defined by Packaging
110 Packaging Seal
110a Length of Packaging Seal
120 Hole in Packaging
200 Septum
300 Battery
r_{seal} Radius of Hole Through the Packaging Seal
r_{side} Radius of Hole Through the Packaging Sidewall
C Clear Button
E Enter Button
S Start Button

Definitions

[0013] As utilized herein, including the claims, the phrase "***hole size***" means the cross-sectional area of a hole or opening. Hole size may be reported as area (*e.g.*, cm^2 or in^2) or may be reported as a variable from which area may be calculated (*e.g.*, radius of a circle (area = (π) ($radius^2$), diameter of a circle (area = (π) ($diameter/2)^2$), length of a side of a square (area = $length^2$), length of a side of an equilateral triangle (area = (($length^2$)/4) (square root of 3), etc.

[0014] As utilized herein, including the claims, ***Poiseuille's Law*** refers to the mathematical equation set forth below which was developed by the French physician Jean Poiseuille to describe the rate of flow of a fluid through a tube based upon the diameter, length and pressure drop along the tube.

$$R = [(\pi)(r^4)(P_1-P_2)] / (8\mu L)$$

Where: R = rate of flow
r = inside radius of the pipe

P_1 = pressure at one end of the pipe
P_2 = pressure at the other end of the pipe
μ = viscosity of the fluid flowing through the pipe
L = length of the pipe

Poiseuille's Law can be meaningfully adapted to calculate an approximation of the size of a hole through packaging by assuming that the hole is a tube with a substantially uniform lumen and equating each of the variables in the equation as set forth below.

R = rate of flow through the hole
r = radius of the hole
P_1 = pressure outside the packaging
P_2 = pressure inside the packaging
μ = viscosity of the fluid flowing into the packaging through the hole
L = length of the hole

Structure

[0015] As shown in FIGs 1 and 2, a first aspect of the invention is an instrument **10** for detecting and reporting the size of a leak in hermetically sealed packaging **100**.

[0016] The instrument **10** can be effectively employed with a wide variety of hermetically sealed packaging **100** ranging from rigid packaging such as poly vinyl chloride tubes, through semi-flexible packaging such as wax-coated cartons and thin-walled polyethylene bottles, to flexible packaging such as bags made from polyethylene terephthalate (*i.e.*, MYLAR®) or polyethylene films.

[0017] Referring to FIGs 1 and 2, the first aspect of the instrument **10** includes a needle **20**, a first pressure sensor **31**, a second pressure sensor **32**, a vacuum pump **40**, a mass flow rate sensor **50**, and a processor **60** with memory **65**. Appropriate tubing **80a**, **80b**, and **80c** (hereinafter collectively referenced as tubing **80**) sequentially interconnect the needle **20**, first pressure sensor **31**, vacuum pump **40**, and mass flow rate sensor **50**, respectively. Appropriate

electrical leads **70a**, **70b**, **70c** and **70d** (hereinafter collectively referenced as electrical leads **70**) electrically connect the processor **60** to the first pressure sensor **31**, the second pressure sensor **32**, the vacuum pump **40**, and the mass flow rate sensor **50**, respectively.

[0018] As shown in FIG. 3, the needle **20** is configured and arranged with a lumen **29** and a sharp pointed distal end **21** effective for piercing a sidewall (unnumbered) of the packaging **100**. A septum **200** is preferably adhered to the sidewall of the packaging **100** - especially when the packaging **100** is highly flexible - prior to piercing of the packaging **100** with the needle **20** in order to maintain a hermetic seal around the needle **20**.

[0019] Referring to FIG. 2, a vacuum pump **40** is sealingly connected to the lumen **29** of the needle **20** by tubing **80**. Once the needle **20** has been inserted through packaging **100**, operation of the vacuum pump **40** is effective for evacuating the gaseous content **102** from the retention chamber **109** defined by the packaging **100** through the lumen **29** of the needle **20** and creating a vacuum within the retention chamber **109**.

[0020] Substantially any type of vacuum pump **40** is suitable for use in the instrument **10**, with selection dependent primarily upon choice of power source (*i.e.*, battery or electrical power lines), desired level of portability (*i.e.*, hand-held or desk-top), and intended use (*i.e.*, testing of large volume or small volume packaging). For most applications, a vacuum pump **40** with a maximum gas volumetric flow rate of about 250 to 1,000 cm^3/minute and capable of pulling a maximum vacuum of about 1-15 lb/in^2, preferably 4-8 lb/in^2, using standard consumer batteries (*e.g.*, AAA, AA, A, C, D or 9-volt batteries) will be sufficient.

[0021] Referring to FIG. 2, a first pressure sensor **31** is employed between the needle **20** and the vacuum pump **40** for measuring and reporting the pressure within the evacuated retention chamber **109**. The internal pressure sensed by the first pressure sensor **31** after the gaseous content **102** has been evacuated from the retention chamber **109** and a steady state vacuum has been established within the retention chamber **109** is the value "P_2" (pressure inside the packaging) in Poiseulle's Law.

[0022] Referring again to FIG. 2, a second pressure sensor **32** is employed to measure and report the atmospheric pressure surrounding the outside of the packaging **100**. The external

pressure sensed by the second pressure sensor **32** is the value "P_1" (pressure outside the packaging) in Poiseulle's Law.

[0023] A cost-effective alternative to employing the second pressure sensor **32** is to utilize the first pressure sensor **31** to sense both the internal and external pressures by taking a pressure reading with the first pressure sensor **31** while the lumen **29** defined by the needle **20** is still in fluid communication with the surrounding environment (*i.e.*, before the needle **20** is inserted into the packaging **100**).

[0024] As shown in FIG. 2, a mass flow rate sensor **50** is positioned downstream from the vacuum pump **40** for measuring the mass flow rate pulled from the evacuated retention chamber **109** by the vacuum pump **40**. The mass flow rate sensor **50** may alternatively be positioned upstream from the vacuum pump **40**. The mass flow rate of interest is the mass flow rate measured after the gaseous content **102** has been evacuated from the retention chamber **109** and a steady state vacuum has been established within the retention chamber **109**. The mass flow rate measured at this stage is the value of "R" (rate of flow through the hole) in Poiseulle's Law.

[0025] Suitable gas mass flow rate sensors **50** for use in the instrument **10** are available from a number of sources, including MKS Instruments of Wilmington, Massachusetts.

[0026] Referring to FIG. 2, the first pressure sensor **31**, second pressure sensor **32**, vacuum pump **40**, and mass flow rate sensor **50** are operably interconnected to a microcontroller or processor **60** by appropriate leads **70** for controlling operation of the various components, and receiving and processing the data signals generated by the various sensors. The processor **60** is connected to a suitable power source, such as a battery **300**, by electrical leads **71**. These components, along with the associated electrical leads **70**, tubing **80** and a power source such as a battery **300**, are preferably retained within a single housing **15** which is equipped with (i) an inlet port **16** configured and arranged to attach to a length of tubing **80a** in order to place the needle **20** into fluid communication with the components retained within the housing **15**, (ii) an outlet port **17** attached by a length of tubing **81** to the mass flow rate sensor **50** for venting gas pumped from the retention chamber **109** by the vacuum pump **40**, and (iii) an access port **18** attached by a length of tubing **82** to the second pressure sensor **32** for placing the second pressure sensor **32** into sensible contact with the surrounding atmosphere.

[0027] Referring to FIG. 1, the front face (unnumbered) of the housing **15** includes the necessary an appropriate user interface components **90** including (i) a power ON/OFF switch **91**, (ii) a data entry device **92**, such as a number pad, and (iii) a display device **93**, such as an LCD screen. The data entry device **92** and display device **93** are operably interconnected to the microcontroller or processor **60**.

[0028] As shown in FIG. 2, the microcontroller or processor **60** includes associated memory **65** for storing data values received from the various sensors **31**, **32** and **50**, and values input through the data entry device **92**.

[0029] The microcontroller or processor **60** is programmed to query a user for (i) the viscosity of the fluid surrounding the evacuated packaging **100** - typically air - which will be utilized as the value "μ" in Poiseulle's Law, (ii) the thickness **100a** of the material from which the packaging **100** is constructed - which will be utilized as a first or sidewall leak value "L" (length of the hole) in Poiseulle's Law, and (iii) the length **110a** of a seal **110** in the packaging **100** - which will be utilized as a second or seal leak value of "L" (length of the hole) in Poiseulle's Law. The microcontroller or processor **60** is further programmed to receive data values for (i) the pressure outside the packaging **100** from the second pressure sensor **32** - which will be utilized as the value "P_1" in Poiseulle's Law, (ii) the pressure inside the packaging **100** from the first pressure sensor **31** - which will be utilized as the value "P_2" in Poiseulle's Law, and (iii) the mass flow rate through the hole **120** from the mass flow rate sensor **50** - which will be utilized as the value "R" in Poiseulle's Law. After receiving these values, the microcontroller or processor **60** then calculates a radius "r" for a hole **120** through the sidewall of the packaging **100** (hereinafter $\mathbf{r_{side}}$) utilizing Poiseulle's Law and the first or sidewall leak value of "L", and calculate a radius "r" for a hole **120** through the seal **110** of the packaging **100** (hereinafter $\mathbf{r_{seal}}$) utilizing Poiseulle's Law and the second or seal leak value of "L". One or both of the calculated "r" values $\mathbf{r_{side}}$ and $\mathbf{r_{seal}}$ are then reported. In appropriate circumstances, one or both of the calculated "r" values can be discarded as extraneous as the calculated value is unrealistic - such as may occur when no leak exists and the value of "R" used in the calculation results in unrealistically small numbers for both $\mathbf{r_{side}}$ and $\mathbf{r_{seal}}$, a leak exists in the sidewall of the packaging **100** and the calculation utilizing the second or seal leak value "L" results in an unrealistically small number for $\mathbf{r_{seal}}$, or a leak exists in a packaging seal **110** and the calculation utilizing the first or sidewall leak value "L" results in an unrealistically large number for $\mathbf{r_{side}}$.

When both r_{side} and r_{seal} are unrealistically small numbers the microcontroller or processor **60** can be programmed to report NO LEAK DETECTED.

[0030] The instrument **10** may be constructed as a portable or desktop unit.

Use

[0031] A unit of packaging **100** having a solids content **101** and a gaseous content **102** is selected for analysis. The power switch **91** is depressed to activate the instrument **10** and the START button **S** is depressed. The instrument **10** displays sequential requests for the user to input values for the viscosity of the fluid surrounding the evacuated packaging **100**, the thickness **100a** of the material from which the packaging **100** is constructed, and the length **110a** of a seal **110** in the packaging **100**, utilizing the data entry device **92**. As an alternative the processor **60** may be preprogrammed with the viscosity of fluids which are commonly encountered as the "atmospheric" gas during such testing, such as air, nitrogen and helium, and the instrument **10** may simply display a menu of these fluid types from which the user may select. After receiving the requested data, the instrument **10** directs the user to insert the needle **20** into the test packaging **100**.

[0032] A septum **200** is optionally adhered to the outer surface (unnumbered) of the packaging **100**. The septum **200** and packaging **100** are perforated by the distal end **21** of the needle **20** a sufficient distance to place the lumen **29** into fluid communication with the retention chamber **109** defined by the packaging **100**. The needle **20** is then left in the inserted position for the balance of the procedure.

[0033] The user then initiates analysis by again pressing the START button **S**. The vacuum pump **40** is activated to evacuate the gaseous content **102** from the retention chamber **109** defined by the packaging **100** and pull a vacuum. The first pressure sensor **31**, second pressure sensor **32**, and mass flow rate sensor **50** are activated to sense the internal pressure, external pressure and mass flow rate through the tubing **80** once the gaseous content **102** has been evacuated from the retention chamber **109** and the pressure within the retention camber **109** has reached steady state. Once these values have been sensed and transmitted to the processor **60**, the pressure sensors **31** and **32**, the vacuum pump **40** and the mass flow rate sensor **50** may be deactivated.

[0034] The processor **60** then utilizes the input and sensed values for fluid viscosity (μ), sidewall thickness (L_{side}), seal length (L_{seal}), external pressure (P_1), internal pressure (P_2) and mass flow rate (R) to calculate a hole size (r) for each of $\mathbf{r_{side}}$ and $\mathbf{r_{seal}}$ using Poiseulle's Law.

[0035] One or both of the calculated "r" values $\mathbf{r_{side}}$ and $\mathbf{r_{seal}}$ are then reported. In appropriate circumstances, one or both of the calculated "r" values can be discarded as extraneous as the calculated value is unrealistic - such as may occur when no leak exists and the value of "R" used in the calculation results in unrealistically small numbers for both $\mathbf{r_{side}}$ and $\mathbf{r_{seal}}$, a leak exists in the sidewall of the packaging **100** and the calculation utilizing the second or seal leak value "L" results in an unrealistically small number for $\mathbf{r_{seal}}$, or a leak exists in a packaging seal **110** and the calculation utilizing the first or sidewall leak value "L" results in an unrealistically large number for $\mathbf{r_{side}}$. When both $\mathbf{r_{side}}$ and $\mathbf{r_{seal}}$ are unrealistically small numbers the microcontroller or processor **60** can be programmed to report NO LEAK DETECTED.

[0036] It is noted that in the event the packaging **100** has multiple holes **120** through the packaging sidewall or multiple holes **120** through the packaging seal **110**, a single aggregate hole size will be reported (*e.g.*, packaging with two different holes **100** through the packaging seal **110** having radii of 2 mm and 3 mm respectively would be reported as a single packaging seal leak having a radius $\mathbf{r_{seal}}$ of 3.15 mm). However, in the relatively rare event that the packaging **100** has at least one hole **120** through the sidewall and at least one hole through the seal **110**, the existence of a hole **120** will be reported but the reported hole size will often be off as the mass flow rate **R** through both types of holes **120** is sensed as a single value and this single value employed within Poiseuille's Law as though the entire mass flow rate is passing through a hole **120** of a single length **L** (*e.g.*, either the length **L** of the sidewall or the length **L** of the seal **110**) when in actuality the length **L** of the hole **120** through the sidewall will typically be several orders of magnitude smaller than the length **L** of the hole **120** through the packaging seal **110**.

[0037] The testing procedure can then be repeated by pressing the CLEAR button **C** followed by pressing the START button **S**.

I claim:

1. An instrument comprising:
   (a) a needle having a lumen operable for perforating a hermetically sealed packaging so as to place the lumen of the needle in fluid communication with a retention chamber defined by the packaging;
   (b) a vacuum pump in fluid communication with the lumen defined by the needle effective for evacuating gaseous content from the hermetically sealed packaging to form an evacuated retention chamber;
   (c) a mass flow rate sensor in sealed fluid communication with the lumen defined by the needle for sensing a mass flow rate pulled through the lumen from the evacuated retention chamber by the vacuum pump and transmitting a mass flow rate signal;
   (d) a first pressure sensor operative for sensing an external pressure on the hermetically sealed packaging and transmitting an external pressure signal;
   (e) a second pressure sensor for sensing pressure within the retention chamber defined by the packaging and transmitting an internal pressure signal,
   (f) a display device;
   (g) a user input device;
   (h) a memory device for receiving and storing
      (1) a value for the fluid viscosity of the external gas,
      (2) a value for the packaging wall thickness, and
      (3) a value for at least one packaging seal length; and
   (i) a processor interconnected and programmed to (1) receive the mass flow rate signal, (2) receive the external pressure signal, (3) receive the internal pressure signal, (4) communicate with the memory device to obtain the fluid viscosity value, packaging wall thickness value and packaging seal length value, (5) calculate a first hole size value for a hole through the packaging wall utilizing Pouseuill's Law and the value for the packaging wall thickness, (6) calculate a second hole size value for a hole through at least one seal utilizing Pouseuill's Law and the value for at least one seal length, and (7) display at least one of the first and second hole size values.

2. A method comprising the steps of:

(a) perforating a hermetically sealed packaging so as to place a lumen in fluid communication with a retention chamber defined by the packaging;

(b) evacuating a gaseous content from the retention chamber through the lumen so as to form an evacuated retention chamber;

(c) sensing mass flow rate through the lumen from the evacuated retention chamber;

(d) sensing an external pressure of a gas surrounding the evacuated retention chamber;

(e) sensing an internal pressure within the evacuated retention chamber;

(f) inputting into electronic memory (1) a fluid viscosity value for the external gas, (2) a value for the thickness of the packaging walls, and (3) a value for the length of at least one seal;

(g) calculating a first hole size value of a hole through the packaging wall from the sensed and input values utilizing Pouseuill's Law and the value for the thickness of the packaging walls;

(h) calculating a second hole size value of a hole through at least one seal from the sensed and input values utilizing Pouseuill's Law and the value for the length of at least one seal; and

(i) reporting at least one of the first and second hole size values.

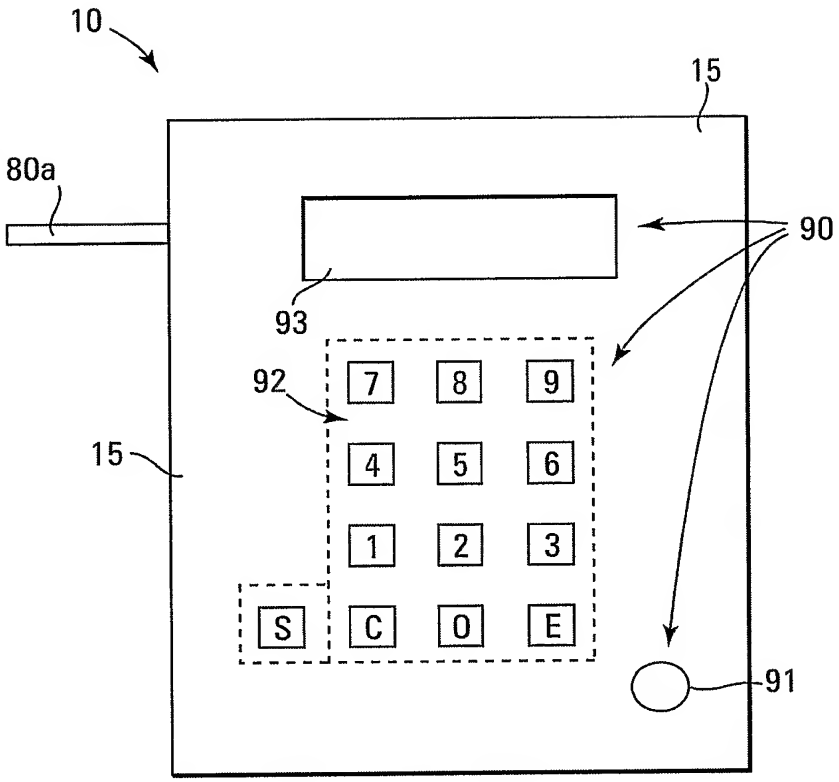

Fig. 1

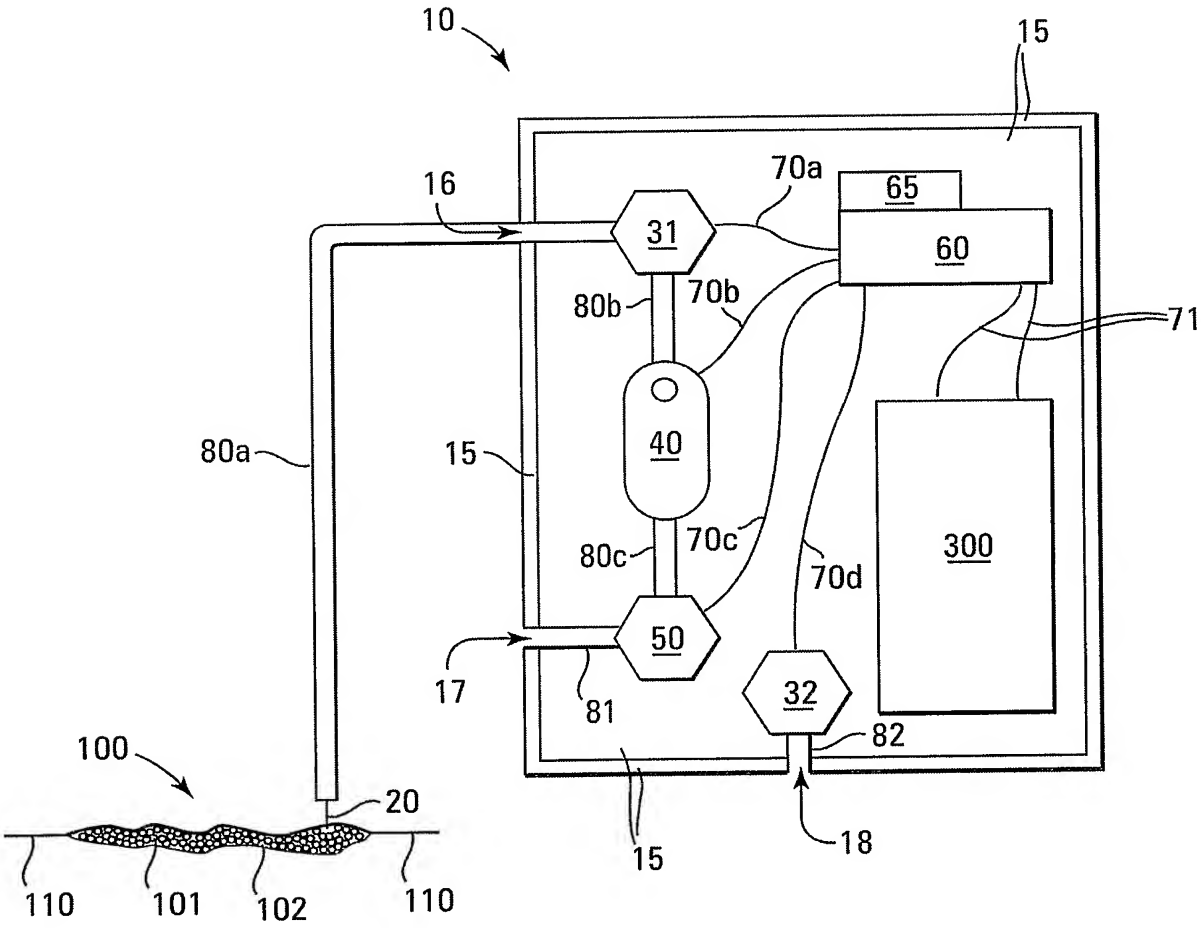
10
15
16
70a
65
31
60
80b
70b
71
40
80a
15
300
80c
70c
70d
50
17
81
32
82
100
20
18
15
110
101
102
110

Fig. 2

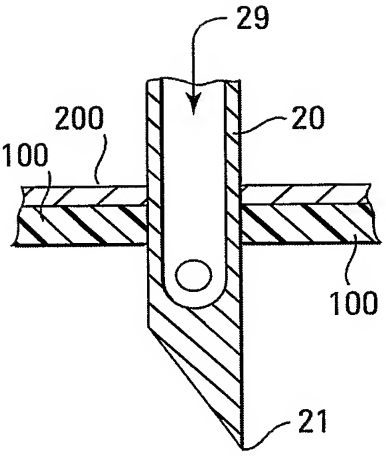

Fig. 3

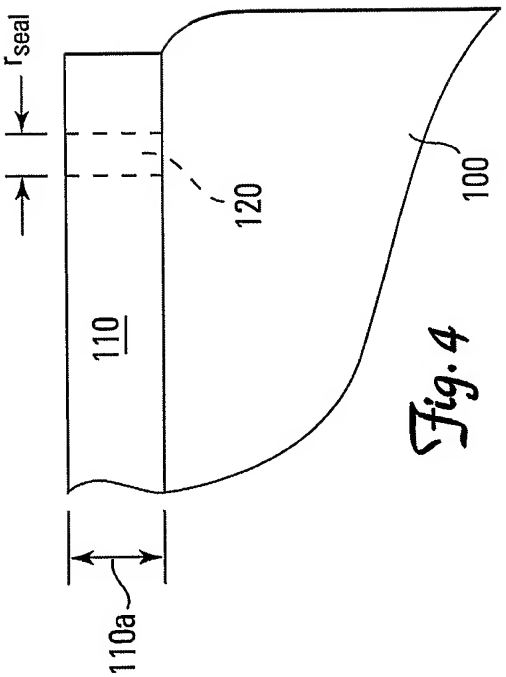

Fig. 4

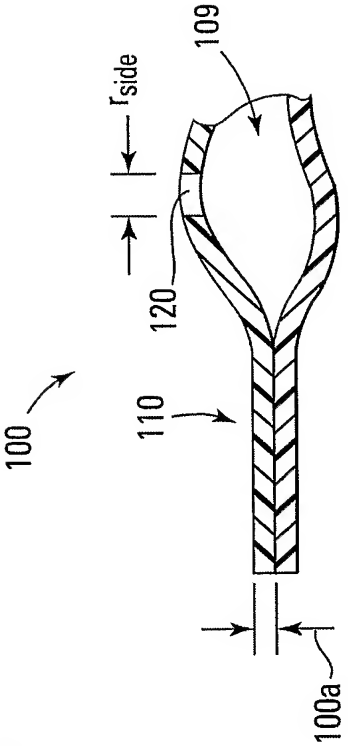

Fig. 5